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DYNAMICS OF SPECIES COMPOSITION IN THE HERBACEOUS-SUBSHRUB LAYER OF PEDUNCULATE OAK (*QUERCUS ROBUR* L.) PLANTATIONS FOLLOWING CANOPY CLOSURE IN A MOIST, RELATIVELY FERTILE SITE TYPE IN ZHYTOMYR POLISSIA

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Background. In recent decades, the area of mature oak forests in Ukraine has been declining due to clear felling. Additionally, the existing network of protected areas is insufficient to encompass the full diversity of natural oak forests. Given these challenges, research is needed to assess plant diversity in forest plantations of different ages established after clear felling, based on forest site type classification.

Materials and Methods. The research was conducted in the Dyvlyn Forestry, part of the Branch "Luhyny Forestry" of the State Specialized Forest Enterprise "Forests of Ukraine" in Zhytomyr Region, Ukraine. The species composition was examined in pedunculate oak (*Quercus robur* L.) plantations of different ages (10 years and 60 years) and old-aged natural forests (120 years) in moist relatively fertile forest sites. Geobotanical, forestry, and silvicultural methods were employed for data collection and analysis.

Results. This study determined the species composition of herbaceous and subshrubby plants in a 120-year-old natural oak forest *Quercetum* (*roboris*) *franguloso* (*alni*) *caricosum* (*brizoides*). The herbaceous-subshrub layer exhibits considerable species diversity, with 15–28 species in 120-year-old natural oak forests, 35–47 species in 60-year-old plantations, and 35–51 species in 10-year-old plantations.

Conclusions. The projective ground vegetation cover was found to be 80–90 % in 120-year-old oak stands and 80–85 % in 10-year-old plantations. The results indicate a predominance of forest species in all stands, with the lowest proportion recorded in 10-year-old plantations (68 %). In contrast, 60-year-old plantations and mature oak forests exhibited nearly identical proportions of forest species (91 and 90 %). The Sørensen similarity index between the herbaceous-subshrub species composition of 10-year-old plantations and 120-year-old forests was 0.51, increasing to 0.66 when comparing 60-year-old plantations with mature stands. The advance regeneration of tree species comprised 6–8 species in 10-year-old plantations, 4–5 species in 60-year-old plantations, and 5–7 species in mature oak forests. It was found that the understory (shrub species) closure varied, reaching 50 % in 10-year-old plantations, 40–50 % in 60-year-old plantations, and 50–60 % in the natural oak forest.

Keywords: biodiversity, projective cover, grass, shrubby and woody plant species, Sørensen species similarity index, ecological and coenotic species groups

INTRODUCTION

Among the anthropogenic factors that significantly influence the rate and scale of vegetation change, forestry activities play a major role. Within this sector, deforestation is particularly impactful (Khryk & Kimeichuk, 2021). Felling is conducted to enhance forest stand productivity (selective felling), prevent the spread of forest diseases and pests (sanitary selective and clear felling), and obtain timber (selective and clear felling). However, all felling activities cause substantial alterations to the forest environment, which, to varying degrees, affect plant and animal biodiversity. These impacts are most pronounced following clear felling for commercial purposes, leading to the destruction of vegetation along skidding tracks due to harvesting equipment movement, as well as in furrows created during soil preparation for reforestation. Additional effects include topsoil disturbance from skidding fallen tree trunks and furrow formation, alterations in soil compaction, moisture levels, temperature, and agrochemical properties, and sudden changes in light availability.

Forestry practices in Ukraine remain largely focused on the clear felling of mature forests and the subsequent establishment of forest plantations, driven by the need to cultivate productive forest stands. However, intensive deforestation during the first half of the 20th century, coupled with this forest management approach, has led to an imbalance in the age structure of Ukraine's forests and an expansion of artificially planted stands. According to the Public report of the head of the State Forest Resources Agency of Ukraine for 2023 (2024), Ukrainian forests are predominantly composed of middle-aged stands, while natural mature and overmature forests account for only 18.7 %. Given Ukraine's vast territory, its location across various natural zones, and the diversity of plant communities within the zones, it is reasonable to assume that some of these ecosystems may be lost in the coming years due to clear felling. Certain forested areas exist in environmentally challenging zones, where tree growth and forest development are naturally constrained. These forests are particularly vulnerable to anthropogenic pressures and climate change. For example, in their study of forest condition, microclimatic features and plant biodiversity as an indicator of forest health in the floodplain forests of the steppe zone (lower reaches of the Samara River), B. A. Baranovski *et al*. highlighted the susceptibility of these forests to human impact (2020). They recommended expanding the network of protected areas to enhance conservation efforts. In Polissia (Ukraine's forest zone), natural peat bog complexes within the Syra Pohonya bog in the Rivne Nature Reserve were investigated (Yuskovets *et al.*, 2024). The study documented the number of such complexes and their dependence on factors such as soil and peat moisture, light availability, nutrient content, and land use intensity. The researchers identified 79 species of higher plants (65 vascular plants and 14 bryophytes), described their ecological associations, and emphasized their sensitivity to specific forestry practices and drainage activities.

Middle-aged stands, which dominate the forest fund of Ukraine, are primarily composed of pure oak stands growing in moist relatively fertile forest sites. Researchers studying the condition and productivity of planted pure oak stands reported lower productivity and poorer health condition compared to mixed stands (Tkach & Rumiantsev, 2022). They also found that pure oak stands exhibited lower resistance to adverse environmental factors, diseases, and pests. Based on their findings, they recommended promoting natural regeneration to establish mixed oak stands, which are more resistant to these challenges and contribute to greater plant biodiversity conservation. These findings align with the research of Kohler *et al*., who reported that the establishment of mixed stands of pedunculate oak supports the conservation of plant species diversity (Kohler *et al*., 2020). In the Tsumanska Pushcha National Nature Park, located in the southern part of western Polissia, Ukraine, researchers examined the age structure and productivity of oak stands in relation to stand age and forest type (Herasymchuk *et al*., 2024). They concluded that pine-oak and oak stands in the park have undergone transformations due to various natural and anthropogenic factors. These changes have resulted in the replacement of oak stands by secondary forests dominated by other tree species across 66–78 % of the area, as well as alterations in the species composition of the herbaceous-subshrub layer. Additionally, extensive areas have been planted with red oak (*Quercus rubra* L.), an alien tree species. In all secondary stands, a distinct assemblage of herbaceous and subshrub species has developed, differing from that of mature oak and pine-oak forests in the region. The researchers also found that oak stands do not fully utilise the site capacity of soils across various forest types. They recommend replacing secondary stands with primary ones and restructuring them through maintenance felling. Similar findings were reported by Kucher *et al*., who classify red oak as a highly invasive species. They also observed that the composition of ground vegetation in red oak stands is severely depleted, with a protective cover of only about 5 % (Kucher *et al.*, 2023).

Research conducted in Zhytomyr Polissia aimed to determine the species composition of herbaceous and subshrub plants, as well as advance regeneration and understory, in forest plantations of varying ages established in fresh relatively fertile forest sites (Ivanyuk, 2020). The study found that following clear felling and plantation establishment, a substantial number of light-loving plants emerge on these sites. However, most of the forest species that were present in the mature forest before felling persist in the open areas, albeit with significantly reduced distribution. Additionally, these species exhibit signs of stress, including stunted shoot and leaf growth and a lack of flowering. As the canopy of the plantations closes, the distribution of forest species increases. Similar findings were observed in studies of herbaceous plant composition in pedunculate oak plantations within fresh relatively fertile forest sites in the forest-steppe zone of Ukraine (Andrushchenko *et al*., 2018). Notably, in 17-year-old oak plantations, the biomass supply of the herbaceous cover was only 9 % lower than that of a 157-year-old stand, measuring 2,587 kg·ha^{-1}.

Due to the decline of the area of mature pedunculate oak forests and the insufficient number of protected areas representing the full diversity of natural oak ecosystems, forest-type based research is necessary. Such studies can assess plant diversity in forest plantations of different ages established after clear felling. The data obtained can form the basis for developing forestry measures aimed at improving conditions for the regeneration and expansion of forest species, as well as identifying areas for potential conservation.

The aim of the study was to identify patterns in the restoration of species composition of herbaceous and subshrub plants, advance regeneration and understory species following the canopy closure of oak plantations in moist relatively fertile forest sites.

MATERIALS AND METHODS

The research was conducted in Dyvlyn Forestry, part of the Branch "Luhyny Forestry" of the State Specialized Forest Enterprise "Forests of Ukraine" in Zhytomyr Region, Ukraine. Specific subcompartments were selected in nature forests and plantations through random sampling using the Forest Fund of Ukraine subcompartment database developed by SE "Ukrderzhlisproekt" (The Forest Fund …, 2017). Registration books of forest plantations from Dyvlyn Forestry were used to select plots of pedunculate oak (*Quercus robur*) forest plantations of different ages (10 years and 60–70 years) within the same natural formation (Mesophytic deciduous broadleaved and mixed coniferous broadleaved forests), and to specify details of their establishment technologies. The plantation techniques used in different periods are similar and representative of Zhytomyr Polissia (**Table 1**), allowing for broader generalisations.

Table 1. **Mensuration characteristics of sample plots established in oak stands in moist relatively fertile forest sites**

No of sample plot	No. compartment / subcompartment	Composition, %	Age, years	Stand quality class	Relative density of stocking	Stock, m^3·ha^{-1}
1	39 / 26	100 % – oak, + aspen, + birch	120	II	0.60	250
2	39 / 3	100 % – oak	120	II	0.62	303
3	25 / 1	80 % – oak, 20 % – hornbeam, + birch	121	II	0.54	242
16	5 / 36	100 % – oak	10	II	0.95	12
17	6 / 9	100 % – oak, + birch	10	II	0.96	14
18	23 / 13	90 % – oak, 10 % – birch, + aspen	10	II	0.96	12
25	1 / 25	80 % – oak, 10 % – birch, 10 % – aspen	61	II	0.70	204
26	1 / 26	90 % – oak, 10 % – aspen, + birch	66	II	0.74	234
27	5 / 21	100 % – oak, + aspen, + birch	61	II	0.72	204

Note: oak = pedunculate oak (*Quercus robur*), aspen = Eurasian aspen (*Populus tremula*), birch = silver birch (*Betula pendula*), hornbeam = European hornbeam (*Carpinus betulus*)

Sample plots of 1 ha (100×100 m) were established following the method described by O. Ye. Pakhomov & V. B. Petrushevskyi (2021). Within each sample plot, 1×1 m (1 m^2) survey quadrats were set up to record plant species and their projective cover (%) (Kuzmishina, 2019). Plant species identification was conducted using the key by D. N. Dobrochaeva *et al*. (1987), and Latin names were verified using the Global Biodiversity Information Facility database (GBIF, 2024). Field research was carried out from April to October 2020. To compare plant diversity, the Sørensen similarity index was applied (Dzyba, 2021). Ecological and coenotic plant groups – forest, forest edge, meadow, marsh, and ruderal – were classified following the method of I. N. Kovalenko (2015).

RESULTS AND DISCUSSION

The species composition of plants in the herbaceous-subshrub layer in the 120-year-old natural oak forest *Quercetum* (*roboris*) *franguloso* (*alni*) *caciosum* (*brizoides*) included 15–28 species, with an average of 19.6 species. These species formed a substantial projective cover of 80–90 % (**Table 2**).

The dominant species contributing to projective cover included *Anemone nemorosa*, *Convallaria majalis*, *Fragaria vesca*, *Pteridium aquilinum*, and *Carex brizoides*. In addition to these, *Betonica officinalis* and *Cruciata glabra* were consistently present across all sample plots. *Galium intermedium*, *Melica nutans*, and *Molinia caerulea* were also abundant in some sample plots. The total number of forest species within the sample plots varied widely, ranging from 13 to 25 species, with an average of 17.7. Several species, including *Dryopteris carthusiana*, *Maianthemum bifolium*, *Milium effusum*, *Stellaria holostea*, *Polygonatum odoratum*, *Trientalis europaea*, *Vaccinium myrtillus*, *Campanula trachelium*, *Hypericum maculatum*, *H. montanum*, *Thalictrum aquilegiifolium*, *Viola odorata*, and *Molinia caerulea*, were not found in all sample plots. Most of these species were at the edge of their ecological range, and their absence in certain plots may be due to unsuitable conditions during stand formation and growth. A notable finding is the presence of *Lilium martagon*, a species listed in the Red Data Book of Ukraine, which was recorded in one of the three sample plots.

Table 2. **Species composition of the herbaceous-subshrub layer in forest plantations after crown closure in moist relatively fertile forest sites and natural oak forests *Quercetum* (*roboris*) *franguloso* (*alni*) *caciosum* (*brizoides*)**

Species name	Projective cover and plant presence on sample plots in forest plantations of different ages and mature forest								
	10-year-old			60-year-old			120-year-old		
	16	17	18	25	26	27	1	2	3
1	2	3	4	5	6	7	8	9	10
Forest species									
Anemone nemorosa L.	+	+	+	45	50	50	40	45	50
Athyrium filix-femina (L.) Roth	-	-	-	+	-	-	-	-	-
Betonica officinalis L.	+	+	+	+	+	+	+	+	+
Brachypodium sylvaticum (Huds.) P. Beauv.	+	1	1	1	-	-	-	-	-

Continued of the Table 2

1	2	3	4	5	6	7	8	9	10
Carex montana L.	-	-	-	-	-	+	-	-	-
Carex pilosa Scop.	+	+	+	-	-	-	-	-	-
Carex sylvatica Huds.	-	+	-	+	-	+	-	-	-
Convallaria majalis L.	+	+	+	8	5	5	5	5	5
Cruciata glabra (L.) Opiz	-	+	+	+	+	+	+	+	+
Digitalis grandiflora Mill.	-	+	-	+	-	+	-	+	+
Dryopteris carthusiana (Vill.) H. P. Fuchs	-	+	-	+	+	-	+	-	-
Epipactis helleborine (L.) Crantz	-	-	-	+	+	+	-	-	+
Fragaria vesca L.	1	1	1	1	1	1	1	1	1
Galium intermedium Schult.	-	-	-	3	3	3	-	-	5
Hylotelephium maximum (L.) Holub	-	+	-	+	+	-	-	-	-
Lathyrus niger (L.) Bernh.	+	+	+	+	-	+	+	-	+
Lilium martagon L.	-	-	-	+	+	-	-	-	+
Luzula pilosa (L.) Willd.	+	1	+	1	+	+	-	+	+
Maianthemum bifolium (L.) F. W. Schmidt	-	-	-	+	+	-	+	-	-
Melittis melissophyllum subsp. *carpatica* (Klokov) P.W.Ball	-	+	-	+	+	+	-	-	-
Milium effusum L.	-	-	-	+	+	-	+	-	-
Neottia nidus-avis (L.) Rich.	-	-	-	+	-	+	-	-	-
Origanum vulgare L.	-	+	+	+	+	+	-	-	-
Platanthera bifolia (L.) Rich.	-	-	-	+	-	-	-	-	-
Polygonatum odoratum (Mill.) Druce	-	+	+	3	-	3	-	-	+
Pteridium aquilinum (L.) Kuhn	3	5	5	5	3	1	3	5	5
Rubus saxatilis L.	+	+	-	5	5	5	-	-	-
Stellaria holostea L.	1	1	1	1	1	1	-	-	+
Trientalis europaea L.	+	+	+	+	+	+	-	+	-
Vaccinium myrtillus L.	+	+	+	10	10	8	-	+	-
Veronica officinalis L.	-	-	-	+	+	-	-	-	-
Viola reichenbachiana Jord. ex Boreau	-	+	+	+	+	+	-	+	+
Campanula persicifolia L.	+	+	+	+	+	+	+	-	+
Campanula trachelium L.	-	-	-	+	-	-	-	-	+

Continued of the Table 2

1	2	3	4	5	6	7	8	9	10
Clinopodium vulgare L.	-	+	+	+	-	-	+	-	+
Festuca gigantea (L.) Vill.	-	+	-	-	-	+	-	-	-
Hypericum maculatum Crantz	+	+	-	+	-	+	-	-	+
Hypericum montanum L.	-	+	+	+	+	+	-	-	+
Melica nutans L.	+	+	+	3	3	1	+	-	1
Molinia caerulea (L.) Moench	1	3	3	5	5	5	1	-	-
Scrophularia nodosa L.	-	+	+	+	-	+	-	-	-
Thalictrum aquilegiifolium L.	-	-	-	-	-	-	-	-	+
Viola odorata L.	+	+	-	+	+	-	-	-	+
Viola riviniana Rchb.	-	-	-	-	+	-	-	-	-
Calamagrostis arundinacea (L.) Roth	+	1	+	3	1	1	-	-	-
Moehringia trinervia (L.) Clairv.	+	+	+	+	+	+	-	-	-
Carex brizoides L.	60	70	65	65	70	75	60	65	70
Melampyrum nemorosum L.	1	3	1	3	3	3	+	+	+
Species number	**22**	**35**	**26**	**43**	**32**	**33**	**15**	**13**	**25**
Forest edge species									
Calamagrostis epigejos (L.) Roth	+	+	-	-	-	-	-	-	-
Chamerion angustifolium (L.) Holub	+	+	+	-	-	-	-	-	-
Ajuga reptans L.	+	+	-	-	+	-	-	+	-
Anthriscus sylvestris (L.) Hoffm.	+	+	-	-	-	-	-	-	-
Festuca heteromalla Pourr.	+	-	-	-	-	-	-	-	-
Hieracium umbellatum L.	+	+	+	+	-	-	-	-	-
Hypericum perforatum L.	-	+	-	-	-	-	-	-	-
Persicaria hydropiper (L.) Spach	+	+	+	-	-	-	-	-	-
Veronica chamaedrys L.	1	1	1	+	+	+	-	+	-
Species number	**8**	**8**	**4**	**2**	**2**	**1**	**-**	**2**	**-**
Meadow species									
Carex pallescens L.	+	-	-	+	-	-	-	-	-
Vicia sepium L.	-	-	-	-	-	+	-	-	+
Deschampsia caespitosa P. Beauv.	-	-	-	-	-	-	-	-	+

End of the Table 2

1	2	3	4	5	6	7	8	9	10
Juncus effusus L.	-	+	+	-	-	-	-	-	-
Luzula pallescens Sw.	+	+	+	-	+	+	-	-	-
Lysimachia vulgaris L.	+	+	+	1		+	+		+
Persicaria minor (Huds.) Opiz	-	+	-	-	-	-	-	-	-
Carex hirta L.	+	+	+	-	-	-	-	-	-
Species number	**4**	**5**	**4**	**2**	**1**	**3**	**1**	**-**	**3**
Ruderal species									
Bidens frondosa L.	+	1	-	-	-	-	-	-	-
Galeopsis bifida Boenn.	1	+	+	-	-	-	-	-	-
Elytrigia repens (L.) Nevski	-	+	-	-	-	-	-	-	-
Species number	**2**	**3**	**1**	**-**	**-**	**-**	**-**	**-**	**-**
Total number of species	**36**	**51**	**35**	**47**	**35**	**37**	**16**	**15**	**28**
Total projective cover	**80**	**85**	**85**	**85**	**85**	**85**	**80**	**85**	**90**

Note: projective cover, %; presence, + / -

The 120-year-old natural oak forest contained very few forest edge and meadow species. Forest edge species – *Ajuga reptans* and *Veronica chamaedrys* – were identified in Sample Plot 1 only. Meadow species, including *Vicia sepium*, *Deschampsia caespitosa*, and *Lysimachia vulgaris*, were found in small numbers in Sample Plot 3. The limited distribution of these species may be influenced by the location of the sample plots in relation to the forest edge or the historical development of the stands. No ruderal plant species were observed in any of the sample plots within the natural forest.

In the sample plots established within 10-year-old forest plantations, the number of plant species ranged from 35 to 51, with an average of 40.7, which was 2.1 times higher than in a 120-year-old natural oak forest. Forest species dominated in the young, closed-canopy plantations, accounting for 22–35 species. The most common among them were *Brachypodium sylvaticum*, *Stellaria holostea*, *Molinia caerulea*, *Carex brizoides*, *Melampyrum nemorosum*, and *Pteridium aquilinum*. Notably, the first three species were either absent in the 120-year-old natural oak forest or were found in only one experimental plot. Certain forest species were recorded in only one sample plot within the forest plantations, including *Dryopteris carthusiana*, *Hylotelephium maximum*, and *Melittis melissophyllum* subsp. *carpatica*. These species were also rare in mature forest, with *Dryopteris carthusiana* appearing in only one sample plot.

Conversely, some forest species that were present in the 120-year-old natural oak forest have shown a decline in distribution within the recently closed 10-year-old plantations. For instance, the projective cover of *Anemone nemorosa* was 40–50 % in the mature forest but dropped to less than 1 % in the younger plantations. A similar decline was observed for *Convallaria majalis*, which decreased from 5 % to less than 1 %. The presence of *Galium intermedium* and *Melica nutans* also declined, albeit to a lesser extent. At the same time, certain species, such as *Melampyrum nemorosum and Molinia caerulea*, exhibited the opposite trend, with higher projective cover in the 10-year-old forest plantations. Importantly, *Lilium martagon*, a species listed in the Red Data Book of Ukraine, 2009, was not found in any of the three sample plots within the 10-year-old plantations.

In the 10-year pedunculate oak plantations, forest edge species were well represented, ranging from 4 to 8 species. Among them, *Veronica chamaedrys* was the most widespread. Some species were found in only one sample plot, including *Festuca heteromalla* and *Hypericum perforatum*. In the mature oak forest, *Ajuga reptans* was recorded in only one sample plot, and *Veronica chamaedrys* was also found in a single plot.

The same sample plots contained six meadow species and three ruderal species, with each plot supporting 4–5 meadow species and 1–3 ruderal species. The most common ruderal species were *Bidens frondosa* and *Galeopsis bifida*. The findings suggest that meadow and ruderal species, which likely became established in the early years following clear felling, have persisted in the closed-canopy 10-year-old plantations. The number of meadow species increased from 3 in the 120-year-old natural oak forest to 6 in the younger plantations.

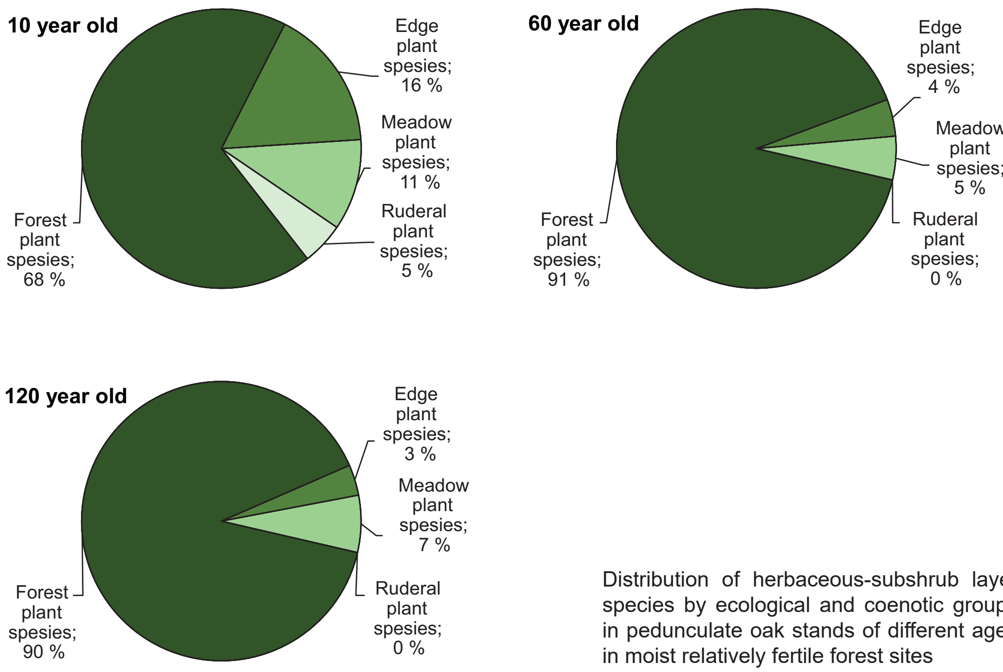
In the 60-year-old pedunculate oak plantations, 32–43 forest species were recorded, a significantly higher number than in 10-year-old plantations and the 120-year-old natural oak forest. *Anemone nemorosa* was the most widespread species, with a projective cover of 45–50 %, similar to that observed in the mature forest. Other species that regenerated included *Convallaria majalis* (5-8 %) and *Galium intermedium* (3 %). The species composition of forest plants in the middle-aged plantations closely resembles that of the 120-year-old natural oak forest. Some species have expanded their distribution within the sample plots, including *Galium intermedium*, *Hylotelephium maximum*, *Luzula pilosa*, *Maianthemum bifolium*, *Neottia nidus-avis*, *Polygonatum odoratum*, *Hypericum montanum*, *Viola odorata*, and *Melampyrum nemorosum*. Additionally, some forest species found in the 60-year-old plantations were absent from the mature natural forest, including *Athyrium filix-femina*, *Carex sylvatica*, *Hylotelephium maximum*, *Melittis melissophyllum* subsp. *carpatica*, *Neottia nidus-avis*, *Origanum vulgare*, *Platanthera bifolia*, *Rubus saxatilis*, *Veronica officinalis*, *Festuca gigantea*, *Scrophularia nodosa*, *Viola riviniana*, *Calamagrostis arundinacea*, and *Moehringia trinervia*.

The Sørensen similarity index for the species composition of the herbaceous-subshrub layer between 10-year-old forest plantations and 120-year-old natural oak forest was 0.51. This value increased slightly to 0.66 when comparing older forest plantations with the mature forest.

Two species listed in the Red Data Book of Ukraine, 2009, were recorded in the 60-year-old forest plantations: *Lilium martagon*, found in two sample plots, and *Platanthera bifolia*, found in one plot. Notably, the number of sample plots containing these species was lower in the 120-year-old natural oak forest.

Forest edge plant species were represented only sporadically: *Ajuga reptans* was found in one sample plot, *Hieracium umbellatum* in another, and *Veronica chamaedrys* in all three plots. Meadow species were also scarce, with *Lysimachia vulgaris* and *Luzula pallescens* recorded in Sample Plot 25, *Luzula pallescens* in Sample Plot 26, and *Vicia sepium*, *Luzula pallescens*, and *Lysimachia vulgaris* in Sample Plot 27. Their distribution was minimal, only *Lysimachia vulgaris* in Sample Plot 25 had a projective cover of 1 %. No ruderal species were found in the 60-year-old pedunculate oak plantations.

The species composition of the herbaceous-shrub layer in moist relatively fertile forest sites was diverse in both the 120-year-old natural oak forest (15–28 species) and the forest plantations of the two studied age groups (35–51 species in 10-year-old plantations and 35–47 species in 60-year-old plantations). The distribution of species across ecological and coenotic groups indicates that forest plants predominate in the sample plots (see **Figure**). The lowest proportion of forest species was observed in the 10-year-old plantations (68 %). However, in the 60-year-old plantations and the mature forest, this percentage was higher and almost identical, making up 91 and 90 %, respectively.



Distribution of herbaceous-subshrub layer species by ecological and coenotic groups in pedunculate oak stands of different ages in moist relatively fertile forest sites

A statistically significant difference in the proportion of forest species was observed between 10-year-old and 60-year-old plantations, and 10-year-old plantations and 120-year-old natural oak forest, with F values ranging from 25.4 to 33.9, which exceeded the critical value of Fcrit (0.95) = 7.71 and p = 0.004–0.007.

These findings suggest that within 60 years after clear felling, the number of forest species in pedunculate oak plantations in moist relatively fertile sites is restored to levels typical of natural forests. It is likely that forest species in young, recently closed plantations were able to survive the direct impacts of logging, plantation establishment, and intensive light exposure. Additionally, the recovery of forest species may have been facilitated by seed dispersal from adjacent forest stands.

The species composition of the understory was relatively diverse, comprising ten species, though their presence varied across sample plots. The highest number of understory species (6–8) was found in 10-year-old forest plantations, while the lowest (4–5 species) was recorded in 60-year-old plantations (**Table 3**). Across all sample plots, regardless of age group or forest origin, only two species – *Quercus robur* and

Populus tremula – were consistently present. Three additional tree species, *Betula pendula*, *Carpinus betulus* and *Malus sylvestris*, were recorded in most plots. *Salix caprea* was found in only one sample plot, likely due to the specific location of that forest stand. Overall, the total projective understory cover was relatively low.

Table 3. **Species composition of understory and advance regeneration in forest plantations after closure in moist relatively fertile forest sites and natural oak forests *Quercetum* (*roboris*) *franguloso* (*alni*) *caricosum* (*brizoides*)**

Species name	Projective cover of species and their presence in sample plots in forest plantations of different ages and mature forest								
	10-year-old			60-year-old			120-year-old		
	16	17	18	25	26	27	1	2	3
Understory									
Frangula alnus Mill.	30	30	35	50	30	30	40	35	40
Rhododendron luteum Sweet	+	+	+	-	-	-	+	-	-
Rubus idaeus L.	5	-	+	+	-	-	+	-	+
Rubus nessensis Hall	5	10	10	+	+	+	10	+	-
Salix cinerea L.	-	-	-	-	+	+	-	+	-
Sorbus aucuparia L.	10	10	5	+	10	10	10	15	10
Species number	**5**	**4**	**5**	**4**	**4**	**4**	**5**	**4**	**3**
Projective cover	**50**	**50**	**50**	**50**	**40**	**40**	**60**	**50**	**60**
Advance regeneration									
Acer platanoides L.	-	-	-	+	-	-	-	-	-
Betula pendula Roth.	+	+	+	+	+	-	+	+	+
Betula pubescens Ehrh.	-	-	+	-	-	-	-	-	-
Carpinus betulus L.	+	+	+	-	+	+	-	+	+
Malus sylvestris Mill.	+	+	+	+	-	+	+	-	+
Pinus sylvestris L.	-	+	+	-	-	-	-	-	-
Populus tremula L.	+	+	+	+	+	+	+	+	+
Pyrus communis L.	+	+	+	-	-	-	+	+	+
Quercus robur L.	+	+	+	+	+	+	+	+	+
Salix caprea L.	-	-	-	-	-	-	-	-	+
Species number	**6**	**7**	**8**	**5**	**4**	**4**	**5**	**5**	**7**
Projective cover	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**

Note: projective cover, %; presence, + / -

Although the number of understory species remained small across all sample plots, their total projective cover was considerable. In 10-year-old forest plantations, it reached 50 %, slightly decreasing to 40–50 % in 60-year-old plantations, while in the natural oak forest, it was the highest, ranging from 50–60 %. However, these fluctuations were relatively minor and not consistent across all sample plots. The species *Frangula alnus*, *Sorbus aucuparia*, and *Rubus nessensis* were consistently found in the understory, forming the core of the projective cover across all sample plots. Additionally, a relict plant, *Rhododendron luteum*, was recorded in all plots within 10-year-old forest plantations and in one plot within the mature forest. Further specialized studies are needed to assess the potential for this species to regenerate after clear felling.

The results of this study provide insights into the processes of plant biodiversity restoration following clear felling, the establishment of pedunculate oak forest plantations, and subsequent cultivation. It was found that in 60-year-old forest plantations, the species composition of the herbaceous-subshrub layer closely resembled that of a 120-year-old natural forest. Similar studies have been conducted in Lithuania, in pine forest plantations and a natural forest (Gustiene *et al.*, 2022). The researchers compared the species composition of herbaceous plants, shrubs, mosses, and lichens in Scots pine (*Pinus sylvestris*) plantations of various ages (2, 6, 10, 30, and 70 years) with that of a 130-year-old natural forest. The highest biomass was observed in 10- and 15-year-old plantations, whereas in 30-, 70-, and 130-year-old stands, the total biomass of ground vegetation was 1.6 to 3.6 times lower. The scientists concluded that species richness is inherent in clear-cut areas and young plantations approaching closure. Similar findings were reported in studies of boreal forests in Canada (Kumar *et al*., 2017). Their research indicated that most species typical of old-growth forests were able to successfully persist in felled areas. This conclusion is also supported by other studies, such as those (Stefanska-Krzaczek, 2015). Another group of Lithuanian scientists examined pine stands of varying ages (up to 115 years) as well as Scots pine plantations (Česonienė *et al*., 2019). Their findings indicated that clear felling did not result in a decrease in species richness. The researchers found that the vegetation in the study area exhibits significant forest-typological diversity, with 23 forest site types and 222 recorded plant species (Bondaruk & Tselishchev, 2021).

Potential directions for future research include examining plant biodiversity restoration processes following clear felling in plantations of different tree species and forest site types, considering the ecological range of each species.

CONCLUSIONS

This study determined the species composition of herbaceous and subshrubby plants in a 120-year-old natural oak forest *Quercetum* (*roboris*) *franguloso* (*alni*) *caricosum* (*brizoides*). The number of species in this plant group ranges from 15 to 28 (mean: 19.6), with a substantial projective cover of 80–90 %. The dominant species included *Anemone nemorosa*, *Convallaria majalis*, *Fragaria vesca*, *Pteridium aquilinum*, and *Carex brizoides*. *Betonica officinalis* and *Cruciata glabra* were common in all sample plots, while *Lilium martagon*, a species listed in the Red Data Book of Ukraine, was found in one plot. The total number of species in the advance regeneration was 5–7, but their distribution was sparse, and their overall condition was unsatisfactory. In the understory, 3–5 species were recorded, with a significant projective cover of 50–60 %. The most common species in this layer were *Frangula alnus* and *Sorbus aucuparia*.

In pedunculate oak forest plantations, the number of forest plant species gradually increases with stand age, ranging from 22–35 species in 10-year-old plantations to 32-43 species in 60-year-old plantations. The dominant species in the herbaceous-subshrub layer in 60-year-old forest plantations, as in the 120-year-old natural forest, is *Anemone nemorosa* with a protective cover of 45–50 %. A comparison of herbaceous and subshrub species composition showed that the Sørensen similarity index increased with stand age. The index was 0.51 between 10-year-old plantations and 120-year-old natural forest and increased to 0.66 between 60-year-old plantations and the mature forest. In 60-year-old plantations, *Lilium martagon* was found in two sample plots and *Platanthera bifolia* in one; both species are listed in the Red Data Book of Ukraine. A significant number of meadow species persisted in 10-year-old plantations, accounting for 10.6 % of the species composition. However, the proportion decreased to 5.0 % in 60-year-old plantations.

The total number of species in the advance regeneration and understory remained constant across experimental plots of different stand ages, with only a slightly higher understory projective cover in a 120-year-old natural forest compared to plantations.

Planted forest stands fulfil important ecological functions, supporting significant biodiversity, and require further research into their structure and functioning. Middle-aged and maturing stands of different tree species should be assessed on a forest-typological basis to identify areas most similar to natural forests and ensure their protection. The results of this study contribute to understanding the dynamics of species diversity in the lower vegetation layers of planted forests, informing strategies for their management and conservation.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Animal Rights: this article does not contain any studies with animal subjects performed by any of the authors.

AUTHOR CONTRIBUTIONS

Conceptualization, [I.I.; V.K.]; methodology, [I.I.; T.I.; V.K.; O.Zh.]; validation, [I.I.; T.I.; V.K.; I.P.]; formal analysis, [I.I.; V.K.; O.Zh.]; investigation, [I.I.; T.I.; V.K.; O.Zh.; I.P.]; resources, [I.I.; T.I.; V.K.; O.Zh.]; data curation, [I.I.; T.I.; V.K.]; writing – original draft preparation, [I.I.; V.K.; O.Zh.]; writing – review and editing, [I.I.; T.I.; I.P.]; visualization, [V.K.; T.I.; O.Zh.], supervision, [I.I.; V.K.]; project administration, [I.I.]; funding acquisition, [-].

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ДИНАМІКА ВИДОВОГО СКЛАДУ ТРАВ'ЯНО-ЧАГАРНИЧКОВОГО ЯРУСУ В КУЛЬТУРАХ ДУБА ЗВИЧАЙНОГО (*QUERCUS ROBUR* L.) З ЧАСУ ЗМИКАННЯ ЇХ У ВОЛОГИХ СУГРУДАХ ЖИТОМИРСЬКОГО ПОЛІССЯ

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Обґрунтування. В останні десятиріччя в Україні відбувається зменшення площ стиглих лісів дуба звичайного внаслідок суцільних рубок головного користування. Науковці також визнають недостатню кількість заповіданих територій цих насаджень, які б охоплювали все різноманіття природних дубових лісів. З огляду на це, необхідними є дослідження стану рослинного різноманіття у лісових культурах різного віку, які створені після суцільних рубок головного користування на лісотипологічній основі.

Матеріали та методи. Дослідження проведено у Дивлинському лісництві філії "Лугинське лісове господарство" ДП "Ліси України". Вивчення видового складу проведено на ділянках лісових культур дуба звичайного (*Quercus robur*) різного віку (10 років та 60 років) і старовікових деревостанах (120 років) у вологих сугрудах. Для досліджень використано методики з геоботаніки, лісознавства та лісівництва.

Результати. У результаті дослідження встановлено видовий склад трав'янистих і чагарничкових рослин у 120-річному природному дубовому лісі крушиново-трясучковидноосоковому (*Quercetum* (*roboris*) *franguloso* (*alni*) *caricosum* (*brizoides*). Видовий склад рослин трав'яно-чагарничкового ярусу досить великий – у 120-річних природних дубових лісах становить 15–28 видів, у 60-річних дубових культурах 35–47 видів і у 10-річних дубових культурах – 35–51 видів.

Висновки. Проєктивне покриття живого надґрунтового покриву у 120-річних дубових деревостанах становить 80–90 %, а у 10-річних дубових культурах – 80–85 %. Виявлено збільшення кількості лісових видів з віком лісових культур. Встановлено, що частка їх у 10-річних лісових культурах становить 68 %, у 60-річних лісових культурах і стиглих дубняках – 91 і 90 %. Розраховано, що значення індексу Соренсена між видовим складом трав'яно-чагарничкового ярусу у 10-річних лісових культурах та 120-річним лісом становить 0,51 і трохи збільшується до 0,66 між лісовими культурами старшого віку та стиглим лісом. З'ясовано, що видовий склад підросту деревних порід у 10-річних дубових культурах складається з 6–8 видів, у 60-річних з 4–5 видів, а у стиглих природних дубових лісах – із 5–7 видів. Виявлено, що зімкнутість підліску (чагарникові породи) у 10-річних лісових культурах становить 50 %, у 60-річних культурах дуба звичайного – 40–50 %, а у материнському дубовому лісі – 50–60 %.

Ключові слова: біорізноманіття, проєктивне покриття, трав'яні, чагарникові та деревні види рослин, індекс видової подібності Соренсена, еколого-ценотична група

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